THE EFFECTS OF SOLDIERS' LOADS ON POSTURAL SWAY

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ABSTRACT

The purpose of the study was to investigate the effects of load weight and load configurations upon postural sway of Soldiers. Measuring postural sway may complement analyses of walking with loads, allowing for quick and efficient determination of how load carriage gear will impact the Soldier. Fourteen Army enlisted men participated in the study. Postural sway was measured while participants stood on a force platform. Soldiers were tested under four load weight configurations comprised of Army clothing and equipment: unloaded (6 kg), fighting load (16 kg), and march load (40 kg) with rucksack weight located close to the body and high in the pack, and a second march load (40 kg) with rucksack weight located far from the body and low in the pack. With an increase in weight, center of pressure excursions increased and Soldiers had to exert more control of the load to maintain balance. As the pack load weight position moved from high and close to low and away from the body, center of pressure excursions continued to increase and the rucksack became quite difficult for a load carrier to control precisely. This study demonstrated that an increase in load weight and a change in rucksack weight position changes both the individual's postural sway and the structure of the sway.

1. INTRODUCTION

The ability of Soldiers to perform duties while carrying backpack loads is important for the success of military operations. Biomechanics and physiology studies focused on walking gait have shed some light on the effects of carrying loads and the ability of the soldier to accomplish marches and perform duties (e.g., grenade throwing, weapon firing) after prolonged marching (Knapik, Harman, and Reynolds, 1996). However, other facets of human movement, such as balance, may significantly affect the capability of Soldiers carrying loads to accomplish marches, negotiate obstacles, perform individual movement techniques, maneuver through Military Operations in Urbanized Terrain (MOUT) scenarios (e.g., climb stairs, execute quick turns, enter through windows), as well as throw objects and fire a weapon. Balance impairments may contribute to injury risk and interfere with a Soldier's ability to successfully accomplish mission tasks and duties.

Researchers have found that balance decreases as subjects' work rates over a period of time increase from 40 W to 125 W (Seliga et al., 1991). Further, the Army Medical Surveillance Activity (2001) stated that, of the serious injuries reported in the U.S. Army during the first five months of calendar year 2001, "falls and miscellaneous injuries" accounted for approximately 30% of the total injuries each month. Given recent injury statistics for the U.S. civilian population, it is likely that at least some of these injurious falls among Army personnel are related to poor balance. The U.S. Bureau of Labor Statistics reported that, in 1996, approximately 60,000 civilian fall related injuries resulted from loss of balance, slips, and trips (U.S. Department of Labor, 1997). Investigations concerned with load carriage and balance may provide information that can be used to improve military pack design and to develop exercise programs that improve Soldiers' balance (Tinetti et al., 1994).

To maintain balance when standing and to avoid a fall, the relative motion between the body's center of mass (COM) and its base of support, usually represented by the feet, must be controlled. This process is referred to as postural sway control. Traditionally, postural sway is quantified by having a person stand in place on a force platform and recording platform output to obtain measurements of the center of pressure (COP), which is the position of the forces acting on the body projected onto a horizontal plane. Studies have found that the carrying of loads affects postural sway. However, while it is unclear what minimum amount of load must be carried or where it must be distributed on the body before the load affects balance, it is clear that, at some load weight, postural sway is affected by load. For example, researchers found that Soldiers who wore a chemical protective clothing ensemble, as compared to a battle dress uniform, displayed no difference in postural sway (Egan et al., 2001). Thus, greater differences in the weights carried on the body may be required to alter balance abilities. Palumbo et al. (2001) found that a commercial off the shelf backpack loaded with 7.7 kg affected limits of stability. Ledin and Odkvist (1993) measured postural sway during standing in test participants without loads on the body and with lead weights placed on the chest and back that totaled 20% of a participant's body weight (BW). They found an increase in anterior-posterior sway area with the added weight on the body; sway area increased from 18.7 mm^2 without a load to 28.4 mm^2 with a load.

Most research into the effects of load carrying on postural sway has examined the impacts of load weight variations and general equipment design parameters.

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Roberts et al. (1996) examined the effects of 13 different designs of load carriage equipment, all weighted with a 36.4-kg load, on postural sway before and after exercise. Prior to exercise, Roberts et al. found that the U.S. Marine study volunteers exhibited no differences in postural sway between the pack conditions and an unloaded condition. After exercise, the authors found that the Marines tended (no statistically significant differences) to have decreased sway with those packs designed to distribute weight to the shoulders, as opposed to the hips. Other researchers found that internal-frame packs, as compared to external frame designs, resulted in improved standing balance ability (i.e., less extensive sway) in men and women (Nelson and Martin, 1982). Filaire et al. (2001) examined the effects of different modes of load carriage on static postures and asserted that keeping the load close to the body's center of gravity and reducing the moment would change static posture the least and reduce spinal curvatures, as compared to other load carriage modes. From these studies of postural stability, it appears that the carrying of large loads affects postural sway and that load position may be related to balance. However, it remains unknown how the location of the COM of a load within a rucksack will affect postural sway.

Although the manner in which load COM may affect standing balance has yet to receive attention, research has been done to investigate the walking characteristics of Soldiers carrying rucksack loads with differing COM locations. This work provides clues as to how the location of the COM may affect postural balance. A study was performed on the effects of COM positions of loads on the biomechanics of Soldiers' walking gait and on the energy cost of carrying loads while walking (Obusek et al., 1997). In this study, Obusek et al. found that the metabolic cost of walking was markedly decreased when the COM of a 35-kg load, carried in an external-frame backpack, was located close to the back and high on the upper trunk, as compared with a load COM that was away from the back and low on the trunk. While the relationship between balance and energy cost during gait remains unclear, it is clear that location of loads affects the load carrier during walking.

1.1 Stochastic Model for Analysis of Postural Sway

Does an increase in postural sway with an increase in load weight or a change in load position matter? In the studies of postural sway as affected by the carrying of loads, only COP excursion length and area have been examined. These measures relate to the movement of the body's COM relative to the base of support. However, Collins and De Luca (1993) asserted that the dynamic characteristics of the COP time series data provide important insights into postural sway that are not seen when only the anterior-posterior or medio-lateral displacement of the COP relative to the body's base of support is investigated. Collins and De Luca postulated that "the movement of the COP during quiet standing can be modeled as a system of coupled, correlated random walks, i.e., the motion is considered to be the result of a combination of deterministic and stochastic mechanisms." Collins and De Luca proposed that COP trajectories be analyzed and interpreted using a general stochastic model, which they referred to as stabilogram-diffusion analysis (SDA), in order to help explain the strategies used by the postural control system to maintain equilibrium during quiet standing. The mean square displacements of COP against time are determined to obtain a stabilogram-diffusion plot.

From a random-walk analysis, the following parameters are then determined: diffusion coefficients, scaling exponents, and critical point coordinates. The diffusion coefficients reflect the level of stochastic activity of the COP. The values of scaling exponents indicate the tendency of movement in a particular direction to continue in the same direction in the future. Collins and De Luca (1993) maintained that the postural control system uses an open-loop control scheme (i.e., the system operates without feedback) over the short term, as evidenced by an increasing (decreasing) trend in the past implying an increasing (decreasing) trend in the future. Collins and De Luca further maintained that, over the long term, the postural control system uses a closed-loop control scheme (i.e., the system operates with feedback). This is evidenced by increasing (decreasing) trends in the past leading to decreasing (increasing) trends in the future. Thus, according to Collins and De Luca, the COP tends to move away from some equilibrium point during short-term intervals and tends to return to a relative equilibrium point over longer-term intervals. The change from open-loop to closed-loop control of standing posture is denoted by the critical point, which is a change in slope of the stabilogram. Thus, two distinct postural control patterns emerge and are utilized: an open-loop control scheme over the short term and a closed-loop control scheme over the long term.

Investigating the effects of load carriage on COP trajectories of Soldiers using these methods may yield important information about how load affects these two distinct patterns of postural control. During the closed-loop control period, if the stochastic nature of the COP decreases with an increase in load, Soldiers may have to increasingly control their posture (to prevent a fall) with a muscular response that places them at an increased risk for injury.

1.2 Purpose of Study

The purpose of this study was to investigate the effects on postural sway of increasing load weight (6 kg, 16 kg load, 40 kg load) and changing load weight position

(load carried in rucksack high on the trunk and close to the body or low and away from the body). It was hypothesized that increasing weight would increase body sway area and reduce stochastic activity over the long term. Further, as load weight position was moved further away from the body and lower in the pack, sway area would continue to increase and stochastic activity would change relative to carrying the load close to the body and high in the pack. We examined the data using both traditional methods and the SDA method devised by Collins and De Luca (1993).

2. Methods

Fourteen Army enlisted men participated in the study (Table 1). Informed consent was obtained and the study was conducted in accordance with Army Regulation 70-25 (Use of Volunteers as Subjects in Research). Volunteers were recruited from among the men and women enlisted personnel who serve as human research volunteers assigned to Headquarters and Headquarters Detachment, U.S. Army Soldier Systems Center, Natick, MA. Exclusion criteria included: a history of back problems and previous orthopedic injuries that limited the range of motion about the shoulder, hip, knee, or ankle joint. Prior to participation in the study, all volunteers underwent a medical screening, physical examination, and review of records by a physician.

Table 1. Means (and SDs) of Volunteers' Characteristics

Age (yr)	19.57	(2.31)
Height*(m)	1.75	(0.07)
Weight (kg)	74.11	(5.98)
Time in Service (mos)	7.57	(2.24)

*11 of 14 volunteers measured for height

2.1 Load Conditions

We tested the Soldiers under three load weight configurations comprised of Army clothing and equipment: unloaded (6 kg), fighting load (16 kg), and march load (40 kg). In all configurations, the Soldiers carried a molded plastic training M16A1 rifle at the ready position. The unloaded configuration consisted of combat boots, socks, T-shirt, and shorts. The fighting load consisted of the unloaded outfit plus a helmet, an armor vest, and a cloth vest with pouches on the front (a MOLLE Fighting Load Carrier). The pouches contained a canteen filled with water, dummy grenades, and dummy ammunition. The march load consisted of the fighting load plus a backpack (a MOLLE Rucksack and Frame) loaded with a 20-kg steel weight. The weight, held in place by foam blocks, was placed in one of two positions within the pack. This resulted in two distinct mass center locations (Figure 1), one with the mass center located close to the wearer's back and high in the pack, near the shoulders. The other location was far away from the wear's back and low in the pack, about even with the waist. The exact COM position for each configuration was determined by employing established methods to take measurements (Norton et al., 2002).

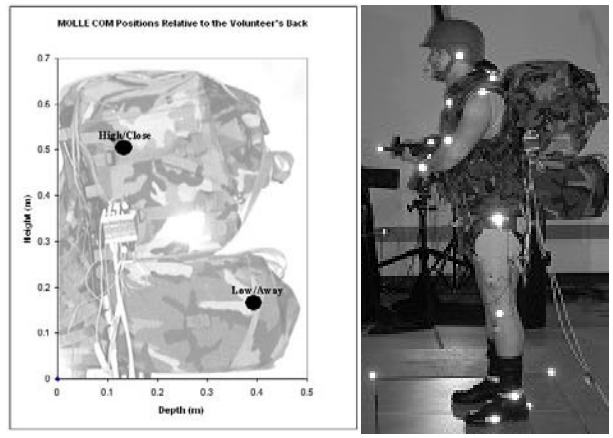

Fig. 1. Two backpack mass center locations relative to the back and a Soldier with the march load.

2.2 Experimental Measures

To establish a foot placement position for each of the load conditions, a Soldier-volunteer stood on a sheet of paper (0.76 m x 0.46 m) with eyes focused straight ahead and weight evenly distributed on both feet. The Soldier assumed a relaxed standing posture with feet placed in a comfortable position. The position of each foot was marked on the paper. We measured the marked locations to obtain stance width and stance angle (McIlroy and Maki, 1997). Foot placement position for each load condition was established at the beginning of the test session, prior to any other activities. For each volunteer, the foot position recorded for a load condition was then used during postural sway testing of that condition. No statistically significant load condition effects were found for stance width or stance angle (Schiffman et al., 2004).

For the postural sway testing, the Soldiers stood, looking straight ahead, in a comfortable and relaxed position on a force plate. Placement of the feet on the force plate was controlled throughout testing as determined by the earlier foot placement measurements. The order in which the Soldiers were exposed to the four load configurations was based on a quasi-Latin square approach. Testing of each load consisted of 10 successive, 30-s trials of standing in place. A 45-s break was provided after every two trials. After every tenth trial, a 5-min break was provided.

2.3 Data Recording and Processing

Kinetic data were collected using an 800 x 400 mm force plate (MODEL OR6-5, AMTI, Inc., Watertown,

MA, 907-kg Fz capacity) interfaced with a data acquisition system. Data were collected with a microcomputer running LabVIEW 6i with a data acquisition board (National Instruments, Austin, TX, USA). The voltage output from the force plate was sampled at 1000 Hz. For the traditional measures of center of pressure (COP), the force plate output was filtered with a low-pass Butterworth filter (cut-off frequency of 10 Hz) and converted to physical units (N and N·m), eliminating phase shift using forward and backward passes.

The traditional measures of postural sway calculated from the force plate output reflected movements made to maintain the body in a standing posture. The measures were total boundary of COPxy (designated as COP_B) and total excursion lengths for the center of pressure paths of COPx, COPy, and COPr (designated as COP_{LX}, COP_{LY}, and COP_{LR}, respectively). In this study, COPx corresponded to the anterior-posterior (forward-backward movement) COP time series and COPy corresponded to the medio-lateral (right-left movement) time series. The COPr was the resultant planar motion. Total boundary of COPxy (COP_B) was calculated by determining the total range of movement in the X and in the Y directions and then multiplying the two, which yielded the largest area that the COP trace fell within. The excursion variables were calculated as the total length of the COP paths in the X direction, the Y direction, and the R (resultant) direction (Prieto et al., 1996). Larger boundary values and larger excursion values indicate greater sway.

In addition to calculating traditional COP measures, we applied the SDA to the COP trajectories. For this analysis, data were left unfiltered, but were down sampled from 1000 Hz to 100 Hz and then converted to physical units. Collins and De Luca (1993) established using force plate data sampled at 100 Hz for conducting SDA analysis. Hurst scaling exponents were computed from the resultant log-log plots for the short-term (Hxs, Hys, Hrs) and the long-term (Hxl, Hyl, Hrl) regions of the linear-linear plots and used to examine the change in structure of postural sway a function of load condition. The short-term region refers to the first region of the stabilogram-diffusion plot, which extends from time interval of 0 s to time interval of 1.3 s, on average, for this data set. The long-term region refers to the remainder of the diffusion plot, from time interval of 1.3 s to time interval of 30 s. Classical Brownian motion, H, equals 0.5. Values less than 0.5 indicate an increasing (decreasing) trend in the past that implies a decreasing (increasing) trend in the future, i.e., negatively correlated. Values greater than 0.5 indicate increasing (decreasing) trends in the past that imply increasing (decreasing) trends in the future, i.e., positively correlated.

2.4 Statistical Analysis

All statistical analyses were accomplished using SPSS 12.0. For analysis of the effects of load conditions on each dependent measure, we averaged the data across a volunteer's ten trials under a condition to obtain a single score on each measure for each load condition. (Reliability of the measures was determined and was found to range from fair to substantial.) A one-way repeated measures analysis of variance (ANOVA) with four levels was then run on each of the traditional postural sway measures (COP_B, COP_{LX}, COP_{LY}, COP_{LR}) and on the Hurst exponents, for a total of ten analyses. The four load conditions were ordered as follows: unloaded (6 kg), fighting load (16 kg), march load (40 kg) with COM located high and close, and march load (40 kg) with COM located low and away. Alpha was set at .05 and significant findings were corrected for multiple comparisons using a step-up sequential Bonferroni procedure (Hommel, 1989). A significant ANOVA finding was followed up with a trend analysis performed using a within-subjects polynomial contrast. To control for multiple follow-up trend analyses, corrections were applied using again the modified Bonferroni procedure. Means and standard deviations for the traditional measures of postural sway are included in Table 2; the summary data for each of the Hurst exponents are in Table 3.

Table 2. Means and Standard Deviations for Traditional Measures of Postural Sway Under Each Load Condition

Variable	Load Condition	Mean	SD
COP_B (cm^2)	Unloaded	2.56	1.35
	Fighting	4.51	2.11
	March / High Close	8.83	2.91
	March / Low Away	11.99	7.53
COP_{LX} (cm)	Unloaded	22.15	3.70
	Fighting	26.86	5.05
	March / High Close	31.50	5.70
	March / Low Away	32.66	8.89
COP_{LY} (cm)	Unloaded	14.01	4.37
	Fighting	15.87	6.18
	March / High Close	21.80	6.53
	March / Low Away	26.86	9.72
COP_{LR} (cm)	Unloaded	28.91	5.73
	Fighting	34.09	7.81
	March / High Close	42.53	9.38
	March / Low Away	47.40	14.27

Note. Larger values indicate greater sway.

Table 3. Means and Standard Deviations for Hurst Exponents Under Each Load Condition

Variable	Load Condition	Mean	SD
Hxs	Unloaded	0.81	0.03
	Fighting	0.83	0.04
	March / High Close	0.82	0.05
	March / Low Away	0.79	0.04
Hxl	Unloaded	0.23	0.11
	Fighting	0.18	0.08
	March / High Close	0.12	0.13
	March / Low Away	0.20	0.12
Hys	Unloaded	0.81	0.05
	Fighting	0.81	0.06
	March / High Close	0.84	0.05
	March / Low Away	0.85	0.06
Hyl	Unloaded	0.19	0.08
	Fighting	0.19	0.10
	March / High Close	0.14	0.08
	March / Low Away	0.15	0.07
Hrs	Unloaded	0.81	0.03
	Fighting	0.82	0.04
	March / High Close	0.82	0.04
	March / Low Away	0.81	0.05
Hrl	Unloaded	0.23	0.09
	Fighting	0.19	0.07
	March / High Close	0.13	0.12
	March / Low Away	0.20	0.10

Note. Values < 0.5 indicate a negatively correlated trend; values > 0.5 indicate a positively correlated trend.

3. RESULTS

3.1 Univariate ANOVAs for Load Effects

None of the traditional measurement variables (COP_B, COP_{LX}, COP_{LY}, COP_{LR}) met the assumption of sphericity for repeated measures ANOVAs. Therefore, the Greenhouse-Geisser adjustment was applied to the degrees of freedom in analyzing each of the measures. Using the adjustment and correcting for Type I Error with the modified Bonferroni, each dependent measure was found to be significantly affected by the load variable.

For the Hurst exponents derived from SDA, all dependent variables were consistent with the assumption of sphericity for repeated measures ANOVAs. After correcting for Type I Error with the modified Bonferroni, the ANOVAs revealed that three of the six Hurst exponents were significantly affected by the load variable. These were Hxl, Hys, and Hrl.

3.2 Trend Analysis

For the traditional measures of postural sway, tests of within-subjects contrasts revealed a significant linear trend for each of the measures (COP_B, COP_{LX}, COP_{LY}, COP_{LR}; Figures 2 and 3). For the Hurst exponents, a significant linear trend was found for Hys (Figure 4) and a quadratic trend was found for Hxl and Hr (Figure 5). These trends were found to be significant after correcting for Type I Error with the modified Bonferroni (Table 4).

Table 4. Follow Up Trend Analysis for Significant Repeated Measures ANOVAs

Variable	*p* Value	*F* (*df* = 1,13)	Trend
COP_B	.000	28.46	Linear
COP_{LX}	.000	23.94	Linear
COP_{LY}	.000	34.41	Linear
COP_{LR}	.000	30.57	Linear
Hxl	.013	8.19	Quadratic
Hys	.000	24.22	Linear
Hrl	.026	6.27	Quadratic

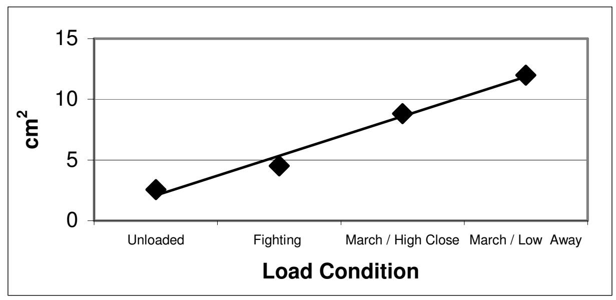

Fig. 2. Linear trend for COP_B as a function of load condition.

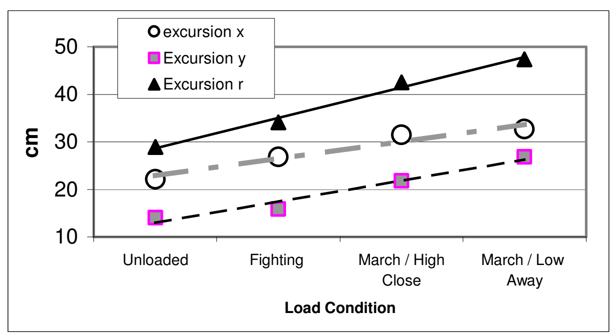

Fig. 3. Linear trend for COP_{LX}, COP_{LY}, COP_{LR} as a function of load condition.

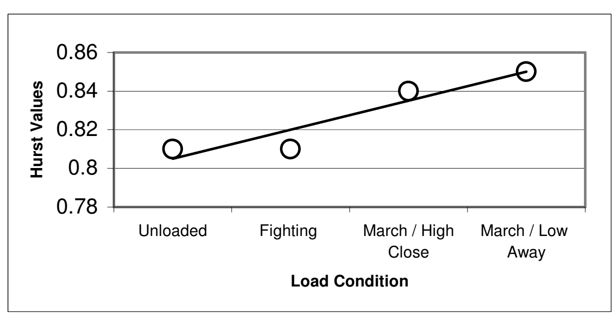

Fig. 4. Linear trend for Hys as a function of load condition.

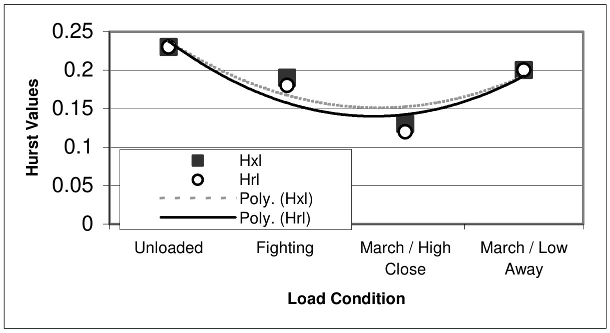

Fig. 5. Quadratic trends for Hxl and Hrl as a function of load condition.

4. DISCUSSION

4.1 Traditional Measures

As load weight increased, the total excursions of COP increased and the total bounded area increased. Increases in COP excursion indicate that more frequent corrections are being made to maintain balance as the load weight increases (Maki et al., 1990). Further, as load weight increases, more muscle activity or mechanical work may be required to make the corrections.

We found that, not only load weight, but also where the load was positioned affected postural sway. In the research by Obusek et al. (1997), carrying a load low and away from the back, rather than close to and high on the body, increased the energy cost of bearing the load while walking. In the present study, a load placed low and away, as compared to close and high on the body, increased postural sway. The increased sway is an indication that the load carrier had to expend more effort (i.e., more mechanical and physiological work) to maintain balance when the pack load was low and away from the body. An increased effort to remain balanced may have resulted in the increased energy cost during walking reported by Obusek et al. Additionally, studies of walking with loads indicate that a greater proportion of the stride cycle is spent with two feet on the ground as the load on the body becomes heavier (Kinoshita, 1985). This reflects an adaptive strategy to maintain balance while walking. Given that the extent of sway during standing was found in the present study to be sensitive to load variations, measurement of postural sway may obviate the need for the extensive studies of walking often associated with load carriage research. Thus, it is possible that assessments of postural sway will provide a quick and efficient method for determining how load carriage gear will impact the Soldier.

Previously, Egan et al. (2001) found that wearing the U.S. Army chemical protective ensemble did not affect standing balance. It may have been that the protective ensemble did not weigh enough to affect balance or that the weight of the ensemble was more or less evenly distributed over the body so as not to affect balance. However, in the current study, we found that, even by adding 10 kg to the unloaded body, with that mass consisting of the fighting load, the excursion and the bounded area of postural sway increased. It is important to note that Egan et al. used the traditional measures to quantify postural sway, and not the stabilogram-diffusion methods. It is not known whether the more sensitive SDA methods would have yielded different results.

The trend analysis we performed on the data from the present study shows that, once Soldiers are wearing 16 kg of gear, their standing balance changes relative to wearing no load. Palumbo et al. (2001) found that wearing a pack load of 7.7 kg altered limits of stability during active postural sway testing compared with wearing no pack or load. Similarly, Lee and Lee (2003) found that stability limits during standing changed when a 12-kg load was held in the hands versus holding nothing. Also, Ledin and Odkvist (1993) determined that postural sway during standing increased when loads equaling 20% BW were carried on the body, compared to an unburdened condition. Clearly at low load weights, ranging from 7.7 to 16 kg, the weight carried affects standing balance. This has implications as the Army moves to a lighter, more mobile force. Decreasing the weight carried by the Soldier will improve balance ability. However, even with light loads, where the weight is carried is important to the effort required in maintaining balance. Future research should examine the effects on Soldiers' balance of the positioning of light loads on the body.

4.2 Stochastic Analysis

Although we found a significant linear trend for Hys (short-term period) across load conditions, the range in the values of Hys was quite small. All load conditions tended to demonstrate a positive correlation, with movements in one direction implying future movements in the same direction. Still, the unloaded and the fighting load conditions tended to exhibit more stochastic or random behavior than either of the march loads on the Hys variable. Over the short-term region, there is not enough time to make corrections to postural sway, even when the behavior has some structure to it. It is because of this inability to make corrections over the short term that we recommend that the focus in future investigations be on the long-term periods of postural control.

We found quadratic trends for both Hxl and Hrl. For these variables, there was somewhat more stochastic activity with the unloaded condition than with the remaining three load conditions. Increasing the load on the body by adding the fighting load resulted in more structured dynamics to maintain postural equilibrium. The

addition of the march load with the COM high and close to the load-carrier's back further increased the structure of the postural movements. Under this condition, compared with the unloaded and the fighting load conditions, it is likely that more control of postural sway was required because of the heavy weight on the body. As the Soldiers swayed away from their equilibrium point, the momentum of the load created a lag effect that required corrective action back towards the equilibrium point. When the load was high and close, the Soldiers had the flexibility to explore their sway limits, but the cost was the need to attend to and return to their balance point, yielding a structured postural behavior. Whether the flexibility this load position afforded is attributable to the load being placed high on the back or close to the back requires further attention. Future research should address carrying loads close to the trunk, but either high on the back or low on the back, in order to assess whether the high or the low load position affords greater flexibility in postural corrections.

In contrast to the march load located high and close to the back, the march load with the load positioned low and away from the wearer was a difficult load to control. This was reflected by the relatively large center of pressure excursions obtained in the traditional measures and the higher values obtained for Hxl and Hrl when the march load was low and away from the back, as opposed to high and close. It appears that carrying the load low and away from the back resulted in the Soldiers being unbalanced and continually attempting to tightly control their postural sway to maintain their standing position. Also, corrections in one planar movement may have necessitated corrections in a different planar movement. Thus, the Soldiers may have been unable to anticipate future postural corrections, which may be an indication of saturated control. As the trend analysis revealed, this postural behavior with the march load carried low and away from the body resulted in a less structured, more stochastic pattern than the load located high and close to the body did.

Although the Hxl and Hrl values for the low and away march load are similar to those for the unloaded and the fighting load conditions, it is likely that the unloaded and fighting load conditions are stochastic in nature for a different reason than the low and away load is. With relatively light loads on the body, less control needs to be exercised to maintain balance. That is, the Soldiers did not have to actively control their sway with the two lower weight loads.

Interestingly, Roberts et al. (1996) found that, prior to a fatiguing exercise, balance/stability measures did not change as function of backpack design. However, the authors found that, after exercise, an internal-frame pack tended to elicit better performance on static postural tests, compared to an external frame. They hypothesized that, when the load is carried low on the hips in an internal-frame pack, it is easier to control than an external-frame pack designed to carry the load high. However, Roberts et al. make no mention of where the weight was located within each pack or where the measured COM of each pack was. So, whether pack design or precise weight placement within the pack influenced their results remains unknown.

While the traditional, quantitative measures of the center of pressure time series provide quick and efficient determination of how a specific load carriage system impacts the Soldier's postural sway, stabilogram diffusion analysis yields insights into the structure of the center of pressure time series. Such information can serve as the basis for improved predictive methods to guide the development of new load carriage systems, without the need for extensive testing of prototypes on Soldiers.

In future analyses of Soldiers' postural balance while carrying loads, we will investigate electromyographic activity during standing to determine if more muscular work is being performed with an increase in load weight. We are also interested in determining whether muscle activity is influenced by the location of loads within the rucksack. We hypothesize that carrying the load low in the pack and away in the body requires more muscular work to maintain equilibrium while standing than carrying the load high and close to the back does.

5. SUMMARY

Increasing load weight borne by the Soldier increased postural sway during standing. Moving the mass center of a backpack load away from the load carrier and lower in the pack was associated with an increase in postural sway. The postural behavior also became less stochastic as load weight increased. However, as the load position was changed from high and close to low and away from the body at the heaviest load, postural behavior became less structured. A load placed low and away in the rucksack may be quite difficult for a load carrier to control precisely. In contrast, a load placed close to and high on the back of the load carrier resulted in a load that, although it required more control to balance, was easier and more predictably managed.

Load carriage studies that examine the relationship among postural sway, walking gait, and Soldier performance are needed to enhance our understanding of the efficacy of the postural sway measures. Future work will examine whether increased muscular or mechanical work is associated with the increase in postural sway.

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